Coal and the Industrial Revolution, 1740-1869

Gregory Clark (UC-Davis, Economics) and David Jacks (Simon Fraser, Economics)
gclark@ucdavis.edu

'England's a perfect world! has Indies too!
Correct your maps: Newcastle is Peru.'[1]

How important was coal to the Industrial Revolution? Despite the huge growth of output, and the grip of coal and steam on the popular image of the Industrial Revolution, recent cliometric accounts have asserted coal mining made a negligible contribution to national productivity growth. In contrast both Tony Wrigley and Kenneth Pomeranz have placed coal at the center of the Industrial Revolution. This paper re-examines the role of coal, utilizing new data on coal rents and on the prices of coal and of alternative fuels such as wood. We conclude coal output expanded in the Industrial Revolution because of demand increases from population and income growth, transport improvements, reduced taxation, and developments in iron and steel. But that expansion could have occurred at any time before 1760. Further our coal rents series suggest that English possession of coal reserves made a negligible contribution to Industrial Revolution incomes.

Introduction

Coal has played a curious role in the history of the Industrial Revolution. In the popular imagination — the Industrial Revolution *is* coal, steam, iron, factories, and railways. And for an earlier generation of economic historians—T. S. Ashton, Fernand Braudel, Roy Church, J. H. Clapham, Phyllis Deane, Michael Flinn, and John Nef—coal was indeed at the heart of the Industrial Revolution.[2] Roy Church notes in his history of the coal industry, for example, "It is difficult to exaggerate the importance of coal to the British economy between 1830 and 1913" (Church, 1986, p. 758).

---

[1] John Cleveland (1651), "Upon the Coal Pits about Newcastle upon Tine."
[2] See Ashton (1948), Braudel (1981), Church (1986), Clapham (1926), Deane (1965), Nef (1932).

Yet "cliometric" accounts of the Industrial Revolution produced from the 1980s on—those of Deirdre McCloskey, Nick Crafts, Knick Harley, and Joel Mokyr, for example—make coal only a bit actor.[3] Despite enormous increases in output the coal industry is credited with little of the national productivity advance either directly, or indirectly through linkages to steam power, metallurgy, or railroads. McCloskey (1981) does not even list it among the revolutionized sectors of the Industrial Revolution.

But in another round of revisionism coal has recently risen to prominence again in accounts of the Industrial Revolution, most noticeably in the work of Anthony Wrigley and Kenneth Pomeranz (Wrigley (1988), Pomeranz (2000)). Both these authors argue that the switch from a self-sustaining organic economy to a mineral resource depleting inorganic economy was a central feature of the British Industrial Revolution. Pomeranz's account of the Industrial Revolution has recently been dubbed "Coal and Colonies" by one reviewer.[4] Britain had accessible deposits of coal near population centers, whereas in China they were distant and inaccessible in the north-west. But the exploitation of the coal in the Industrial Revolution required dramatic technological advance ("technological expertise was essential to Europe's coal breakthrough" (Pomeranz (2000), p. 66), which was why an Industrial Revolution came only after the 1760s.

These contrasting views of the role of coal in the Industrial Revolution can be portrayed in figures 1-3. Figure 1 shows estimated cumulative output in millions of tons from the north east coalfields in England compared with the estimated real price of coal in London, supplied by the north east, measured in the prices of the 1860s.[5] In real terms the price of coal to consumers

[3] McCloskey (1981), Crafts (1985), Crafts and Harley (1992), Mokyr (1990).
[4] Vries (2001).
[5] Thus the price in the 1740s was 23/- in nominal terms, greater than the 1860s nominal price of about 21/-. But between the 1740s and 1860s all prices rose by 57%, so in real terms the 1740s price is much higher at 36/- per ton.

in London nearly halved over the course of the Industrial Revolution, at a time when annual output from coalfields expanded 12-fold.

The "cliometric" account of coal in the Industrial Revolution can be represented in figure 2. The horizontal axis shows cumulative output since the beginning of extraction in the north east coal field, and the vertical axis a hypothetical real cost of extraction per ton, which rises slowly as total extraction increases. But real extraction costs are only moderately higher at the cumulative output of the 1860s than at cumulative output of the 1740s. Also plotted are actual cumulative outputs by 1745 and 1865. In this portrayal the supply of coal is elastic. When demand increased so did output, with little increase in the price at the pithead. But the same expansion of output could have occurred earlier or later had demand conditions been appropriate. The movement outward in the rate of extraction was caused by the growth in population and incomes, and by improvements in transport and reductions in taxes which reduced the wedge between pithead prices and prices to the final consumers. Coal experienced a mere 'shift along the supply curve, rather than outward movement of the curve'; that is, output soared because of increased input utilization and not due to the development of 'new techniques allowing existing resources to produce cheaper or better' (Mokyr, 1990, 110).

An alternative picture, favored by Wrigley and Pomeranz, where the industry was subject to major efficiency gains is that of figure 3, where the cost of extraction in 1740 actually increased sharply with increased cumulative output. Greater extraction with the technology of the 1740s would have caused sharp increases in real coal prices. As Michael Flinn notes,

> The increase in the supply of coal at prices that in real terms were constant or even diminishing was, of course, made possible by an unceasing flow of technical

> advances. The number and economic significance of these developments have been much underrated by historians in the past. (Flinn (1984), p. 442).

In the northeast, for example, the coal seams were at variable depths across the coalfield. By the 1740s the shallow, easily worked seams had been largely exploited and further output depended on sinking deeper shafts with greater associated costs of excavation, haulage, drainage, and ventilation. Technological advances in the coal industry from 1740 to 1860 shifted the extraction cost curve downwards. The coal industry was only able to respond to increases in demand in the Industrial Revolution era because of this technological advance. With the technology of the 1740s energy costs would have been radically higher by the 1860s, and much of the Industrial Revolution growth would have been choked off.

If we just consider pithead prices and output then these very different accounts are observationally equivalent. Indeed figure 4 shows what happened to the real Newcastle price of coal as cumulative output rose. This picture is consistent with *either* a slowly rising cost of extraction and no significant technological advance between the 1740s and the 1860s *or* a steady and dramatic advance in the efficiency of the extraction technology. For the decline in real prices in London, as is well known, was caused by declining shipping and distribution costs coupled with a decline in taxation of the coal trade. In real terms the costs of coal close to the pithead actually increased moderately.

Thus discriminating between these stories of what happened in the coalfields requires further information. Below we develop a test of whether the supply curve for coal was believed to be close to horizontal in the eighteenth and early nineteenth century by looking at the behavior of mineral rents.

The Coal Supply Curve

What was the coal supply curve had the technology of the 1740s remained unimproved until the 1860s? To work this out we employ information on the site rents per ton of coal extracted paid to the owners of the land under which the coal seams lay compared to the pithead price of coal. Table 1 shows our calculated price of coal at Newcastle, which is close to the pithead price. The sources are listed in the appendix. Since coal varied greatly in quality we set the level of the Newcastle series calculated for 1740 to 1869 to be equivalent to the pithead prices for the northeast reported by Church for 1882-1913 (Church (1986), pp. 58-9). Table 2 shows average, minimum and maximum site rents per ton by decade for the north east as a percentage of the average pithead price of coal, calculated on the basis of a sample of more than 200 coal leases from the northeast. On average rents were only about 10% of the selling price at the pithead. But also interestingly there is relatively little range in the site rents paid. The maximum site rent at any time is less than 30% of the average Newcastle selling price of coal.[6] We show below that the range of these rents at any time is too low to be consistent with a sharply increasing cost of extraction, as portrayed hypothetically in figure 3. Further these site rents were modest in an industry where there were consistent attempts to limit coal output in the northeast through various alliances of coal producers. If anything these site rents **overstate** the free market rental of coal land would have been.

To have been consistently willing to lease the land for extraction for such modest amounts the owners of the seams with low costs of extraction (based on closeness to the surface, thickness of the seam, or transport costs to the staiths) must have believed that deeper mining was possible at little higher cost. For an option to the owner of an exhaustible asset such as a

[6] This implies extraction costs varied little across the various seams being worked. In contrast extraction costs for oil are now reported to range from $1 for some middle eastern reserves to $15 a barrel for some Russian oil.

coal seam is always to leave the coal in the ground and extract it later if prices are assumed to be likely to increase. The owner of a seam with extraction cost *c* per ton should delay mining as long as

$$E(p_{t+1} - c) \geq (p_t - c)(1 + r) \tag{1}$$

where p_t is the price of coal in year t, and *r* is the rate of return on capital. $(p_t - c)$ is the amount the seam can be leased for per ton in year t, and $E(p_{t+1} - c)$ the expected site rent in year $t+1$. What this says is that if coal seam owners expect site rents to increase at above the rate of return on capital they should just keep the coal underground and wait for more favorable prices. If real extraction costs from new mines and deeper seams were expected to be much higher in any decade such as the 1740s, then the market price of coal would be expected to rise also. The incentive of the owners of the low cost seams would then be to conserve their assets for exploitation at a more favorable time unless the current coal price was already high enough to offer them large profits. Coal left in the ground would increase in value year by year faster than the mineral rents obtained from its extraction could compound if invested in a mortgage or in landed property. What would persuade owners to exploit now would be a situation where enough owners deferred exploitation so that current prices rose sufficiently to make even current exploitation profitable. But this would imply that in any decade some owners had to be deriving high site rents as long as extraction costs were expected to be increasing rapidly.

Figure 5 shows, for example, a simulated extraction path for the coal industry in the northeast, starting in 1740, where extraction costs then on the seams being exploited are assumed to be 4.5 s. per ton (the actual costs in the 1740s for best coal). But costs were expected to rise as new seams were brought into production, with extraction costs per ton given by

$$Cost(Q) = 4.5 + 0.0026Q^2$$

where Q is cumulative output from 1740 on. With this specification the cost curve with cumulative output is as shown in figure 5. By 40 years from 1740, at the extraction rate of that decade, costs would be 23/- per ton with this assumption.

Assume that land owners have no market power and simply decide when to start working their seams. The price of coal at Newcastle is then the extraction cost plus the site rent. The price at London is the Newcastle price plus 17/- shipping and tax cost to the London market. The price in London (in shillings) is assumed to be

$$p_t = 40 - 10q_t \tag{2}$$

where q_t is the million tons of the Newcastle reserves mined in that period. This demand curve is set so that at the actual annual output of the 1740s (q = 1.8 m tons per year) the price in London is close to the actual price that prevailed in that decade, 22.9/-. This implies that the maximum price that would be paid in London for coal is 40/-, and that demand for Newcastle coal in London was relatively elastic with respect to price (the price elasticity at the London price of the 1740s is 1.22 with this demand curve).[7] The return on capital (*r*) is assumed to be 4.5%.

With just these specifications, we can calculate an implied extraction path (prices and quantities) for the decades following the 1740s, if the coal owners expected the technology and the demand to remain the same, and price path which meets condition (1) for the owners of the coal reserves. This is the path is shown in figure 5.

What is interesting for our purposes is that with these realistic specifications of initial costs and pithead prices the coal rents of the 1740s on the easily worked seams in use then are, at

[7]Thus at the point where Newcastle output was 1% of the total reserves per year the price elasticity for Newcastle coal in London would be 12.5.

3.5/- per ton, about 42 percent of the implied Newcastle price of 8.3/-. These rents are about 10 times as great as the rents per ton actually being charged in coal leases in the 1740s (see table 2).

Yet the history of this period is that mineral rents in the north east were low despite persistent attempts to restrict production, which involved in some cases paying colliery owners "dead rents" to not exploit their reserves. Thus in 1770 while there were 31 collieries selling coal to the London market through the Tyne, another 11 collieries were being rented by the "Grand Allies" for a dead rent to keep their production out of the market. One, for example, was St Anthony's colliery, close to the Tyne. The Grand Allies paid £300 a year to keep this colliery out of production for 42 years from 1734 to 1776. In another case the Grand Allies took Stanley colliery out of production in 1793, while paying the mineral owners again a rent of £300 per year until 1817 to keep it closed (Cromar, 1978). These dead rents made no sense if future coal production was expected to come from seams with inherently much higher costs. In that case you would not have to pay owners to persuade them to delay exploiting a colliery. Thus coal owners in the eighteenth century behaved as though they believed their currently worked seams, generally those close to the surface, had little cost advantage on coal seams not yet worked. And among the seams being opened up in any decade there is little sign of much variation in the costs of production.

Total Factor Productivity in Coal Mining, 1740-1869

The evidence from coal rents is that extraction costs were rising only modestly with cumulative output. In this case the total factor productivity (TFP) of the coal mining industry can be estimated reasonably well using the ratio of pithead prices to input costs. Productivity can thus be approximated as

$$A = \prod_{i,j} \frac{\omega_j^{\theta_j}}{p_i^{\alpha_i}}$$

where A is an index of productivity, p_i is the price of output i, and α_i is the share of output i in the value of output, ω_j is the factor price paid to input j, and θ_j is the share of input j in the total payments to inputs. This will be a lower bound on the estimated productivity gains, since it assumes that coal seams were of equivalent quality over time.

Various authors have estimated the composition of costs over our period as is shown in table 3. These show a fairly stable pattern over the interval 1740 to 1869. Mining labor was the most important cost, being more than 42% of all costs including rents of capital. The royalties paid for access to the seams were about 9%, which is very much in line with our estimates for the northeast shown in table 2. Returns on capital were about 20%. Coal used for pumping operations and supplied to miners was 6% of costs, horse fodder 5%. The final 18% was a miscellany of craftsmen's wages, and supplies such as timber, rope, candles, and oil.

Tables 1 to 5 show the data necessary to calculate TFP in coal mining in the north east. While the north east was a minority of the English industry, it was the single most important coalfield throughout this period, so productivity growth in the industry as a whole was unlikely to have differed much for England as a whole from the north east. [8]

Pithead Prices

Coal is anything but a homogenous good, varying widely—both among *and* within mines—in such qualities as thermal content, length and type of burn, and 'sootiness.' So pithead prices were estimated from a variety of printed and archival sources on Newcastle prices and true pithead prices for individual mines from 1740 to 1869 (detailed in the appendix), where they were combined in a regression of the form

$$\ln p_{it} = \sum_i \alpha_i LOC_i + \sum_t \beta_t DUM_t + \varepsilon_{it}$$

where p_{it} is the quoted price from source i in year t, LOC_i is an indicator variable for each of the sources we have on prices of types of coal (such as Wallsend), and DUM_t is an indicator variable for the year. Then the prices obtained were linked to the pithead prices of coal from the northeast reported by Church (1986) for the years 1882 on using export prices as the linking series. The resulting estimated prices, controlling for differences in coal quality, are those shown in the last column of table 1.

Wages

There is no series available for coal miners wages in the northeast in the years 1740 to 1869. Instead we have 38 scattered estimates and measures of hewers wages per shift reported by authors such as Ashton and Sykes, Flinn and Church. These estimates are shown in figure 6. Hewers wages should be a good index of mining wages in general since the wages of some other workers, especially putters (those employed in transporting the coal from the face to the pit bottom or head), were set explicitly in terms of hewers' wages and also there are indications of

[8] Pollard (1983) places the share of the Northumberland and Durham coalfields at one-third for the beginning of the period and one-fourth for its closing. McCord and Rowe (1971) report that the region supplied London with nearly 95% of its coal requirements as late as 1826.

strong correlation between hewers' wages and the whole of those employed in mining, including some lower-level management type positions such as overman (Church, 1986; Griffin, 1977). When we compare these scattered quotes of wages over time to farm wages in the north of England we find that, while there are short run deviations, over the long run of 1740 to 1869 they increase by exactly the same amount. Thus when we regress the ratio of hewers' wages to farm wages (*WH/WA*) on a constant plus a time term, T, measuring years since 1740 we find that the time trend term is both statistically and quantitatively effectively 0. Thus,

$$\frac{WH}{WA} = 2.108 - 0.00024T \tag{3}$$

with the standard error on the coefficient estimate for T being 0.00141. Figure 6 shows also hewers wages as predicted from equation (3), shown as the bold line. As can be seen, for the long run, hewers' wages can be reasonably well approximated by farm wages. Since the major recruitment for labor for the coalfields was farm workers this result is not surprising. Notice also that the hewer in the northeast earned more than double the agricultural wage, as compensation for the danger and unpleasantness of underground working.

Hewers in the northeast also received free housing and coal allowances which are not incorporated in these wage estimates. The housing is included under the capital costs of the mine. The coal allowance is subsumed under the coal consumed at the pithead for pumping and other purposes.

Table 4 shows the resulting decadal estimate of northeast daily coal wages. Also shown are the average daily wages of building craftsmen and their helpers in the northeast. In the productivity estimates we assume that such workers maintaining pit structures and equipment were 10% of total costs.

We assume half of the 18% spent for craftsmen and supplies was for labor. The wage used here is that of northern building craftsmen from Clark (2004).

Coal Rents

The rental payment per ton of coal in table 1 is calculated from leases of coal land. Since mine operators had to undertake large fixed investments in mines coal leases were generally for 21 years or more. The form of the lease in the north east was generally that the lessee paid a fixed rent for all coal extracted up to a certain minimum quantity, and then a payment per unit of output—known as the tentale rent—for all output above the allowance. Often the tentale rent was the same as the fixed payment divided by the allowance. Thus it is possible to estimate from these leases the average coal rents paid per ton of output. A sample of over 200 leases from the 1730s to the 1860s was collected (see Appendix I). From this sample, estimates were made of the general course of lease payments in each decade. In estimating these we again used a regression of the form

$$\ln rent_{it} = \sum_i \alpha_i LOC_i + \sum_t \beta_t DUM_t + \varepsilon_{it}$$

where $rent_{it}$ is the quoted tentale rent from source i in year t, LOC_i is an indicator variable for the location or the colliery, and DUM_t is an indicator variable for the year.

These rental payments we assume to reflect the value of coal land in free competition. Throughout this period, however, colliery owners in the north east attempted, through the 'limitation of the vend', for example, to restrict output and bolster prices. If limitation of output was present earlier in the history of the industry, but not later, it would bias upwards the estimated movement of productivity over these years (see Harrison, 1994). Various studies of competition and monopoly in the industry in these years, however, have generally concluded that the attempt to limit output was generally unsuccessful, due to a poorly designed system of positive and negative incentives (Sweezy, 1938), indifferent enforcement (Hausman, 1984a, 1984b), and an inability to erect substantial barriers to entry (Cromar, 1977; Hausman, 1984a, 1984b).

Fodder

Fodder costs were assumed to be half those of oats and half those of hay. These prices are available from Clark (2004) for England as a whole and are shown in table 4.

Supplies

These we assume to be 9% of costs. There is no clear breakdown of these in the accounts of the industry. We know timber, iron, ropes, candles, and oil all were components. Table 4 shows the estimated prices for timber, iron and candles, which we assign weights of 5%, 2% and 2% respectively in total costs.

Capital Costs

Capital costs in the productivity calculation will be

$$(r+d)p_k$$

where r is the rate of return on mining capital, d the depreciation rate of capital, and p_k the cost per unit of the capital goods employed in mining.

To estimate the cost of mining capital, p_k we used five price series: estimated northeast hewers wages (50%), estimated northern builders wages (20%), the price of bricks (10%), the price of iron (10%), and the price of timber (10%). The weights were those suggested by Roy

Church for circa 1850 (Church (1986), p. 175). The major capital goods in mining were the shaft, the pithead structures and buildings, and railways and wagons. Table 5 shows estimated brick prices for England as a whole. The other prices necessary to construct capital costs are all shown in table 4. Table 5 shows the resulting index of the price of mining capital in the northeast per unit. For comparison Church's index of capital costs for the 1830s to 1860s is also shown. These two series both move little for this interval and are quite consistent.

For the years before the 1850s there are no direct measures on the long-term return on capital in mining, or on the cost of the capital involved. The records needed to calculate an industry-wide average rate of return are no longer extant. Even in the fragmentary records that have survived, accounting practices, especially for the earlier parts of the period, seem to be a jumbled confusion of entries with little delineation between charges for, say, circulating and fixed capital, depreciation, and returns and with little concern for consistent and fundamental accounting principles (Flinn, 1984).

Given this we estimated the return on capital in mining as the average rate of return on bonds and mortgages in the same interval. Most coal mine owners were landowners or merchants in addition (Buxton,1978; Flinn, 1984; Griffin, 1974). Thus the return on investing in mines cannot have strayed too far in the long run from investments in other assets such as mortgages. We took as our rate of return proxy the rate of return on bonds and mortgages in England from Clark (1998). These returns are shown in table 5. They were not much lower than the return reportedly earned in coal mining in the 1850s and 1860s when we get accounts good enough to estimate returns. Table 6, for example, shows some estimates of the net return on mining capital in the UK in the 1850s and 1860s. As can be seen these returns exceed those on bonds and mortgages in the same period by less than 1%. So while we do not have direct measures of the return on capital in mining, it did not exceed the mortgage rate by much. We calculate the rental cost of capital in mining thus as

$$(r + 0.05)\,p_k$$

where r is our measure of the interest cost of capital, 0.05 is allowed for depreciation and for a risk premium, and p_k is the price of capital goods. The allowance for depreciation is in line with estimates in the nineteenth century by Church of the gross return on mining capital compared to the net return. Gross returns, which incorporate capital consumption and depreciation as part of the return, were about double estimated net returns. Table 5 also shows the resulting estimated rental cost of capital in mining by decade.

Total Factor Productivity

Table 7 shows as an index the price of coal at the pithead in the northeast by decade, and the calculated costs of mining coal. The Total Factor Productivity is then just the index of costs divided by the index of pithead prices and is shown in the last column of the table. This index of productivity is shown in figure 7. Even though mining wages rose much faster than the pithead price of coal, overall costs rose only very slightly more than output prices because so many other elements of cost increased much more slowly – coal rents, iron, timber, bricks, and candles in particular. Thus between the 1760s and the 1860s measured productivity rose by only about 10% overall, or at a rate of about 0.10% per year. Remember, however, that this is the lower bound estimate of productivity growth. It assumes that the industry was using coal bearing land of the same quality throughout the period as the land being used in the 1740s. The justification for this assumption is the very low level of coal rents observed for even the earliest period of the northeast industry.

Coal and the Industrial Revolution

This productivity result above is entirely consistent with the modern cliometric interpretation of the coal industry. Output expansion was driven by factors external to the industry – increased urban demands for coal, increased demand from iron production, and reduced taxation and transport costs. In contrast to the estimated 0.10% productivity growth rate of coal mining, productivity in cotton textile production increased by 3.1% per year (Clark (2001b)). TFP in iron and steel manufacturing is estimated to have increased in the same years by about 0.9% per year (McCloskey (1981), p. 114). Further productivity growth in coal mining is much below the 0.55% per year productivity growth for the economy as a whole found by Crafts and Harley (1996). Coal mining really was a bit actor in the productivity advances of the Industrial Revolution drama. The aggregate productivity growth rate in an economy is the sum of productivity growth rates in each sector, weighted by the share of output in that sector in GDP. Thus

$$g_A = \sum_i \theta_i g_{Ai}$$

where g_A is the overall productivity growth rate, θ_i is the share of each industry in GDP, and g_{Ai} is the productivity growth rate of each industry. If we calculate sectoral productivity growth rates on a value-added basis, then the weights θ_i will be value-added in each sector relative to GDP. If we calculate productivity growth rates treating intermediate inputs as factors of production in each industry, then the weights will be the ratio of gross output of each industry to GDP, and these weights will add to more than 1. Over the years 1760-1869 the average share of GDP produced in coal mining was only 1.6%. Thus the contribution of coal **mining** productivity growth to overall TFP growth in the Industrial Revolution era was 0.002% per year. Had there been no productivity growth in coal mining output in the economy in the 1860s would only have been 0.2% less than actually observed. In contrast cotton textiles alone contributed about 0.20% per year to productivity growth. Had the entire textile revolution never occurred output per capita would have been at least 23% lower in the 1860s.

Transport Improvements and Coal Consumption

The major reason for the huge increase in consumption of coal per capita in England in the Industrial Revolution period seems to have been a combination of increased demands for coal from greater populations and higher incomes, increased demands following on improvements in iron smelting technology, reduced taxation of coal used for domestic purposes in cities like London, and declining real transport costs.

The top line in figure 8, for example, shows the price of best coal in London, in shillings per ton, measured in real terms compared to the 1860s. Also shown are the costs of coal of this quality in real terms at the pithead in Newcastle as calculated above, as well as the real transport cost and the real tax burden on the coal trade. 'Transport costs' here mean all the costs in getting coal from the pithead to the final buyer, exclusive of taxes. They thus include insurance costs, the costs of transferring coal between the land and the ships, and of delivering coal to the customers in London. For the 1860s these costs are estimated at 8.21 s. per ton, compared with 6.36 s. per ton for the actual sea freight rate as reported by Harley (Harley (1988), p. 875). For the years 1740-1829 we used Beveridge's data for coal transported to Greenwich Hospital. We link this series to the difference between Newcastle and London prices for best coal for 1830-1869. The real price of coal in London falls by nearly 50% from the 1740s to 1860s as a result of the decline in the tax burden and in transport costs. Had the costs of shipping coal from the coalfields to places like London been the same in real terms in 1740 as in 1860 then production would have been many times greater in 1740.

The Industrial Revolution without Coal?

Above we have implicitly considered the counterfactual "what would Industrial Revolution growth have looked like had there been no productivity advance in coal mining?" The answer has been "very little different." A much more radical counterfactual to consider would be what would have happened had the available coal supply been limited so that after 1770 Britain had depleted its coal reserves. What would the Industrial Revolution have looked like absent British coal?

It depends crucially here what exactly the counterfactual is. A narrower version is that the Dutch, instead of being left coal poor, had received instead the British coal reserves. How would that have changed the Industrial Revolution in England? One thing is clear. The income derived in England from the actual possession of the coal reserves was always an extremely modest share of national income. If we assume all coal mined in England paid the same site rents to land owners as for our sample of leases reported in table in the northeast then the share of national income paid to coal reserve owners would only be 0.1% in the 1740s, rising to about 0.2% in the 1860s. Had the same coal been located only in Scotland, in Ireland, or in the Netherlands the losses to English national income from loss of mineral rents would have been insignificant.[9]

[9] The situation was very different with coal than with Middle Eastern oil producers such as Saudi Arabia where the extraction cost for the oil can be less than 10% of the market price, leading to massive rental payments to producing countries.

The much more important cost from having to rely on coal imports would have come from higher coal prices to final consumers as a result of greater transport costs. But much of the coal mined in England was already shipped considerable distances to final consumers. Between 20% and 33% of all coal mined in England before 1870 reached consumers after a sea voyage, and other coal was carried some distance by canal and rail. Suppose we assume that coal consumption 1740-1869 was as we observe, but all of it had to bear the expense of a sea voyage from another country whose cost was the same as the Newcastle-London voyage. In that case the additional cost of coal to consumers would be a fairly consistent 3.9% of English GDP throughout the years 1740 to 1869 (much more coal was consumed in later years but the transport costs had fallen). This reduction in GDP would not fundamentally change the course of the Industrial Revolution.

Since the coal costs for industries such as iron making or salt making which were very energy intensive and located close to the pits would have been much greater the growth of these industries might have been much more limited. But even if England had not developed a substantial iron industry in the Industrial Revolution era, the productivity gains from iron working were again a minor contributor to the Industrial Revolution.[10] And the less coal was imported for iron making the lower the extra transport cost identified above. Textiles were where the major productivity gains occurred. And the share of energy costs in textile production was small. So in a counterfactual world where the coal reserves were located in Ireland or Scotland or elsewhere in northwest Europe the history of Industrial Revolution England need not have resulted in much slower economic growth.

Equivalently the absence of coal in Ireland, the Netherlands or northwest France does not explain why the Industrial Revolution did not occur there. Throughout this period coal from the

Tyne went not just to London but to the rest of northwest Europe. Thus countries like the Netherlands had access to coal at prices little higher than those of most of southern England through most of the Industrial Revolution period.

A more sweeping counterfactual would have been to suppose that there was no available coal in Europe. This is the counterfactual Kenneth Pomeranz effectively considers when he asserts that the location of accessible coal was one of the two vital factors allowing Europe to have an Industrial Revolution when an equally qualified China did not (Pomeranz (2000)). Without coal, water power, wind power and firewood would have alone served the energy needs of the Industrial Revolution economy. In England by the 1860s about 22 million tons of coal was used for domestic purposes – heating, cooking and lighting (Church (1987), p. 19). The value of this coal at the point of consumption was about 2% of GDP. All of that would have to have been replaced by firewood. This is the energy equivalent of 2,350 m. cubic feet of wood per year.[11] The average reported annual yield of coppiced wood of different species in England in recent years, including an allowance for the small branches which would be bundled into faggots, is 1.27 tons per acre of dried wood, or 97.5 cubic feet of wood.[12] Each acre of managed woodland in England could thus produce the equivalent, in energy terms, of only 0.87 tons of coal per year. To produce firewood in the 1860s equivalent in energy terms to domestic consumption of coal would have required 25 m. acres of land per year, nearly the entire farmland area of England of 26 million acres.

There was, however, in the Baltic region alone, and in British North America, a lot of wood available to the English economy throughout the Industrial Revolution era. Table 8 shows,

---

[10] See McCloskey (1981), Crafts (1985).

[11] Assuming that a lb. of coal contains 12,000 btu., that the dried weight of wood is 29.2 lbs per cubic foot, and that each lb of wood contains the 8,600 btu.

for example, the areas, modern timber areas, modern wood production and wood yield per acre of the countries or regions bordering the Baltic and of the provinces of Canada with water access to the St Lawrence circa 2000. These were the regions England drew its construction timber supplies from in the nineteenth century. This shows that at current production rates, based on smaller forested areas than in the nineteenth century, the Baltic and British North American regions could have easily supplied enough wood to completely replace the energy supplied by coal for domestic purposes.[13]

This alternative energy, however, would have been more expensive than coal, in large part because of its higher transport costs. Figure 9 shows the cost per ton of coal to domestic consumers in England, the cost of domestic firewood per ton of coal-equivalent, and the cost of shipping from St Petersburg a wood volume equal to a ton of coal-equivalent in energy, all normalized by the average day wage of a building worker. Thus the figure shows how many days a building worker had to work to get the fuel equivalent to a ton of coal. As can be seen imported fuel, just based on transportation costs from the Baltic, would have been more expensive than coal. If the costs of production of firewood in the Baltic had equaled that for domestic firewood, then fuel costs in the Industrial Revolution era for domestic consumers of coal would have been about doubled throughout these years. This would have represented in any year a loss of at maximum about 2% of GDP by the 1860s, which is not a dramatic difference.

This just looks at the extra costs to domestic consumers. The other 65% of coal went into industrial uses – iron and steel making, salt pans, brick making. If all of these sectors had used as much energy as before then we would need to add at least another 4% of GDP to the loses

[12] See Begley and Coates (1961), Evans (1984), Rollinson and Evans (1987). Hammersley (1973), pp. 604-5, notes that woodland can produce "up to 100 cubic feet per year."
[13] These current production rates are generally below the estimated sustainable production of woodlands in these countries.

from not having coal. But also the rising demands on the Baltic forests would probably also have led to rising production costs at the source. But most likely here these energy intensive industries would not have located in England – iron as in earlier years would have been imported from the Baltic - with modest costs to the productivity growth of the economy. The strength of these counterfactual calculations gets weaker the further we move from the actual economic circumstances of England in the Industrial Revolution era. So this last conclusion is no more than an interesting suggestion. But it certainly suggests that Pomeranz's conclusions on the vital role of English coal in the Industrial Revolution are equivalently just speculations.

Conclusion

We see above that there is little evidence for significant productivity growth in English coal mining in the Industrial Revolution era, and that the enormous expansion of output of coal in these years owes to factors external to the industry: increased demands for coal from greater populations and higher incomes, increased demands following on improvements in iron smelting technology, reduced taxation of coal used for domestic purposes in cities like London, and declining real transport costs. This conclusion is based in part on the behavior of the owners of coal reserves in the northeast. They did not act as though they believed at any time that there was, with current technology, an impending increase in extraction cost as the seams of coal closer to the surface were exhausted. Instead they consistently leased coal lands for very modest rents per ton, as though they expected little rise in the price of coal in the coming years from the 1740s onwards. Making the assumption that even up to the 1860s there were still large reserves of coal in the northeast unexploited all of which had roughly the same cost of extraction we estimate the total factor productivity of the industry in the northeast from 1740 to 1869 and find that there were only very modest gains. There is little sign of a technological revolution in coal mining. English coal reserves, known and exploited since medieval times, simply found a much larger market in Industrial Revolution England.

As we saw the low coal rents, and the importance of transport and tax costs in the final cost of coal imply that England gained little advantage from actually possessing the coal reserves. An Industrial Revolution based on coal reserves which gave the same pithead price but were located in the Netherlands or Ireland would not have involved a much slower growth rate.

The more radical counterfactual of a Europe that completely lacked accessible coal reserves, or was unable to utilize the deeper English coal seams after the 1760s, is more difficult to analyze. Certainly there were plenty of energy supplies available in the forests of the Baltic and more remotely in British North America and the Russian Arctic. The costs of getting these supplies to English consumers were falling as a result of improvements in sailboats, and the end of the Anglo-French struggle in 1815. Energy for domestic purposes could have been supplied to English consumers at a less than prohibitive cost as late as the 1860s. But this more expensive energy would have resulted in a very different pattern of location for energy intensive industries such as iron production. The effects of this relocation of industrial activity are difficult to analyze. But since, as noted before, the estimated contribution of coal and iron and steel to productivity growth is Industrial Revolution England is so small, the effects before 1870 would still seem to have been modest.

APPENDIX: DATA SOURCES

COAL LEASES:

Hughes (1963).

Durham Record Office: D/Br/B 1, 79, 122, 141, 180, 186, 195; D/CG 6/365, 1450, 1455-57, 1460, 1462; D/DD 140; D/Lo/E 303, 304; D/St/Bl/3/4, 5, 25, 39-40, 66, 69, 72, 108-9, 119; D/X 651/3.

Durham University Special Collections: GB-0033-SHA 393, 423, 431/1a, 3289, 3314, 3327, 3351, 3402, 3403, 3572-4, 3581, 3586.

Newcastle City Library: L347.2 230743, 230745; L622.33; L622.33 63943.

Northumberland Record Office: 2/DE/1/14; BELL/14; BUD/18, 32, 50, 53; JOHN/6/26; JOHN/7, 8; LES 2/30, 32-3, 40; LES/3/34, 44, 46, 50, 56, 62-3, 61, 77-8, 83; WAT/1/5; WAT/3/30, 41, 45, 51, 58, 72, 103-4, 110; WAT/4/21; WAT/5/2, 6, 7, 11-2; ZGR dm/12/n; ZRI/35/24.

Tyne and Wear Archive Service: 3415 CK/8/60, 65; 3415 CK/9/106, 122; DF/WF/29; DS/CAR/11/1-4; DX 973/5/1.

PITHEAD PRICES:

Beveridge (1966), pp. 294-5.

Dunn (1844), pp. 73, 85.

Harley (1988).

Hausman, William J. (personal communication), Newcastle prices from “Brief Against the Petition of Glassmakers.”

Porter (1851), pp. 277-8.

Durham Record Office: NCB/I/JB/2435, 2444, 2454, 2457, 2462, 2466.

Morpeth Records Centre: NRO 1073/1-55.

Newcastle City Library: SL 622.33.

Northumberland Record Office: 2/DE/7/10/1-22; 725/C/2; BUD/32; BUD/53; BUD 54/18-9, 132; FOR/3; WAT/1/26/9; WAT/3/41, 84; ZAN/M13, B3-4.

Tyne and Wear Archive Service: 35/167

LONDON PRICES:

Beveridge (1966) (Greenwich Hospital, Chelsea Hospital, Lord Steward, Navy Victualling, Westminster)

United Kingdom, Board of Trade (1902) (Greenwich Hospital, Bethlem Hospital)

Guildhall Library: Brewers' Company, Dame Alice Owen's Almshouses, Islington. 5478/1-3. 5473/1-5.

WORKS CITED

Ashton, T. S. 1948. *The Industrial Revolution*. Oxford: Oxford University Press.

Ashton, T. S. and Joseph Sykes 1964. *The Coal Industry of the Eighteenth Century.* Manchester: Manchester University Press.

Begley, C. D. and A. E. Coates. 1961. "Estimating Yield of Hardwood Coppice for Pulpwood Growing." *Forestry Commission Report on Forest Research 1959/60*, pp. 189-196. London: Her Majesty's Stationary Office.

Beveridge, W.H. 1966. *Prices and Wages in England from the 12th to the 19th Century, Vol. I.* London: Frank Cass & Co.

Braudel, F. 1981. *The Structures of Everyday Life*. New York: Harper & Row.

Buxton, N.K. 1978. *The Economic Development of the British Coal Industry*. London: Batsford-Academic.

Church, R. 1986. *The History of the British Coal Industry, vol. 3, 1830-1913*. Oxford: Clarendon Press.

Clapham, J.H. 1926. *An Economic History of Modern Britain*. Cambridge: Cambridge University Press.

Clark, Gregory 1998. 'Land Hunger: Land as a Commodity and as a Status Good in England, 1500-1914,' *Explorations in Economic History,* 35 (1), (Jan.), 59-82.

Clark, Gregory 2001a. 'Farm Wages and Living Standards in England, 1670-1869,' *Economic History Review*, 54 (3), (August): 477-505.

Clark, Gregory 2001b. "The Secret History of the Industrial Revolution." Working Paper, UC-Davis.

Clark, Gregory 2004a. “The Price History of English Agriculture, 1209-1914” Forthcoming, *Research in Economic History, 22*.

Clark, Gregory 2004b. ‘The Condition of the Working-Class in England, 1200-2000: Magna Carta to Tony Blair.’ Working Paper, UC-Davis.

Crafts, N.F.R. 1985. *British Economic Growth during the Industrial Revolution*. Oxford: Clarendon Press.

Crafts, N.F.R. and C.K. Harley. 1992. ‘Output Growth and the Industrial Revolution: A Restatement of the Crafts-Harley View.’ *Economic History Review* 45:703-730.

Cromar, P. 1977. ‘The Coal Industry on Tyneside, 1771-1800: Oligopoly and Spatial Change.’ *Economic Geography* 53, 79-94.

Cromar, P. 1978. ‘The Coal Industry on Tyneside, 1715-1750.’ *Northern History*, 14, 193-207.

Deane, P. 1965. *The First Industrial Revolution*. Cambridge: Cambridge University Press.

Dunn, M. 1844. *An historical, geological and descriptive view of the coal trade of the north of England*. Newcastle upon Tyne: Garrell.

Evans, J. 1984. *Silviculture of Broadleaved Woodland*. Forestry Commission Bulletin 62. London: Her Majesty’s Stationary Office.

Flinn, M.W. 1984. *The History of the British Coal Industry, vol. 2*. Oxford: Clarendon Press.

Griffin, A.R. 1977. *The British Coalmining Industry*. Buxton: Moorland Publishing.

Hammersley, G. 1973. “The Charcoal Iron Industry and its Fuel, 1540-1750.” *Economic History Review*, *24*: 593-613.

Harley, C. K. 1988. 'Ocean Freight Rates and Productivity 1740-1913: The Primacy of Mechanical Invention Reaffirmed.' *The Journal of Economic History*, 48 no. 4 (1988) 851-876.

Harrison, A.E. 1994. 'Productivity, imperfect competition and trade reform: Theory and evidence.' *Journal of International Economics*, 36, 53-73.

Hausman, W.J. 1984a. 'Cheap Coals or Limitation of the Vend? The London Coal Trade, 1770-1845.' *Journal of Economic History*, 44, 321-328.

Hausman, W.J. 1984b. 'Market Power in the London Coal Trade: The Limitation of the Vend, 1770-1845.' *Explorations in Economic History*, 21, 383-405.

Hausman, W.J. 1987. 'The English Coastal Coal Trade, 1691-1910: How Rapid was Productivity Growth?' *Economic History Review*, 40(4), 588-596.

Hausman, W.J. 1993. 'Freight Rates and Shipping Costs in the English Coastal Coal Trade: A Reply.' *Economic History Review* 46(3), 610-612.

Hughes, M. 1963. *Lead, Land, and Coal as Sources of Landlord Income in Northumberland between 1700 and 1850*. Ph.D. thesis, Durham University.

Lower, Arthur R. M. 1973. *Great Britain's Woodyard: British America and the Timber Trade, 1763-1867*. Montreal: McGill University Press.

McCloskey, D. 1981. 'The Industrial Revolution: 1780-1860, A survey,' in R. Floud and D. McCloskey, *The Economic History of Britain since 1700*, pp. 103-128. Cambridge: Cambridge University Press.

McCord, N. and D.J. Rowe 1971. *Northumberland and Durham: Industry in the Nineteenth Century*. Newcastle upon Tyne: Frank Graham.

Mitchell, B.R. 1984. *Economic Development of the British Coal Industry, 1800-1914*. Cambridge: Cambridge University Press.

Mokyr, J. 1990. *The Lever of Riches*. Oxford: Oxford University Press.

Nef, J.U. 1932. *The Rise of the British Coal Industry, vol.s I & II*. London: Routledge.

Pollard, S. 1983. 'Capitalism and Rationality: A Study of Measurements in British Coal Mining, ca. 1750-1850.' *Explorations in Economic History*, 20, 110-129.

Pomeranz, Kenneth 2000. *The Great Divergence: China, Europe and the Making of the Modern World Economy*. Princeton: Princeton University Press.

Porter, G. R. 1851. *The Progress of the Nation*. London: John Murray.

Rollinson, T. J. D. and J. Evans. 1987. *The Yield of Sweet Chestnut Coppice*. Forestry Commission Bulletin, 64. London: Her Majesty's Stationary Office.

Sweezy, P.M. 1938. *Monopoly and Competition in the English Coal Trade, 1550-1850*. Cambridge: Harvard University Press.

United Kinggdom, Board of Trade 1902. *Wholesale and Retail Prices.*

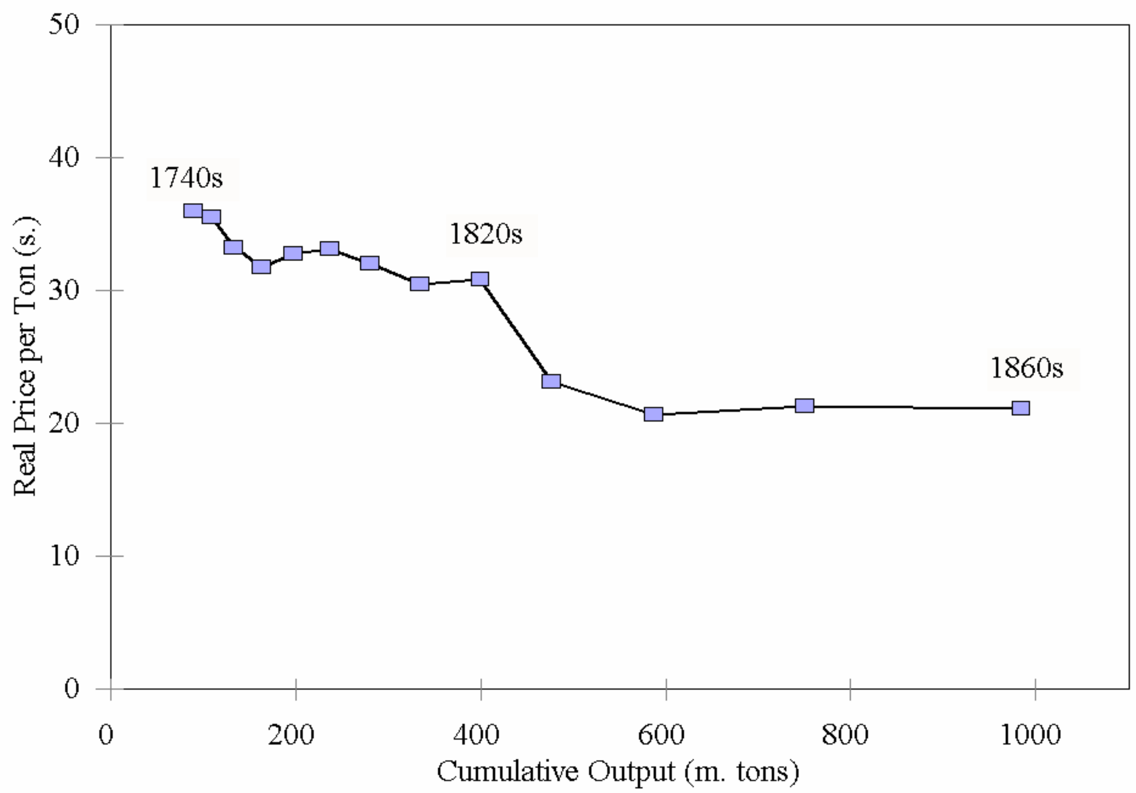
Vries, P. H. H. 2001. 'Are Coal and Colonies Really Crucial? Kenneth Pomeranz and the Great Divergence,' *Journal of World History, 12(2), 407-446.*

Wrigley, E.A. 1962. 'The Supply of Raw Materials in the Industrial Revolution,' *Economic History Review* 15(1), 1-16.

Wrigley, E.A. 1988. *Continuity, chance and change*. Cambridge: Cambridge University Press.

Wynn, Graeme. 1981. *Timber Colony: A Historical Geography of Early Nineteenth Century New Brunswick*. Toronto: University of Toronto Press.

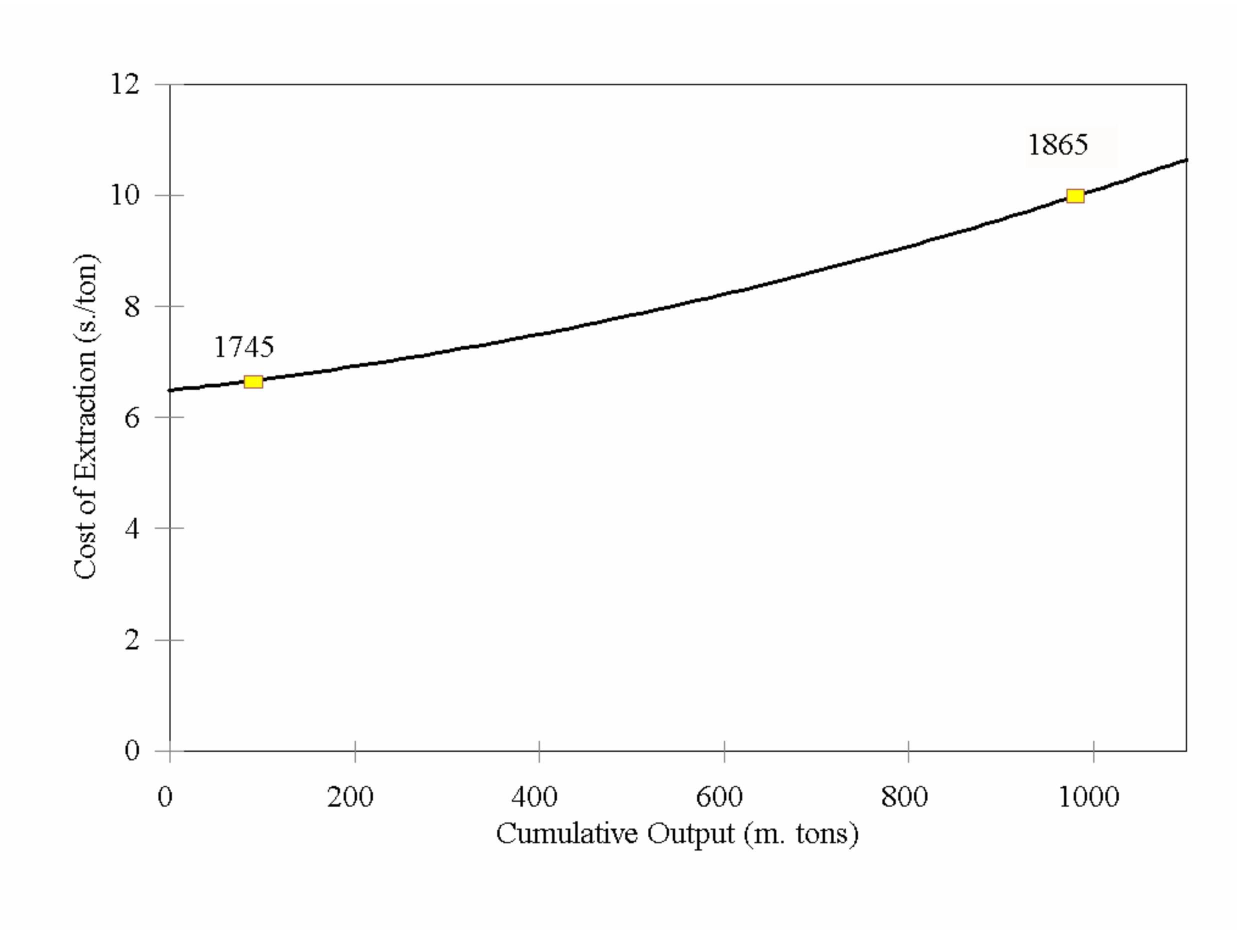
Figure 1: Real prices in London and cumulative output from the north east coalfields, 1740s-1860s



Note: The price is standardized to that of Wallsend coal. The cumulative output in 1730 from the north east is assumed rather arbitrarily to be 81 million tons. It would not affect the picture shown here if it were made higher or lower. Prices are deflated by a cost of living index for manual workers derived in Clark (2004b).

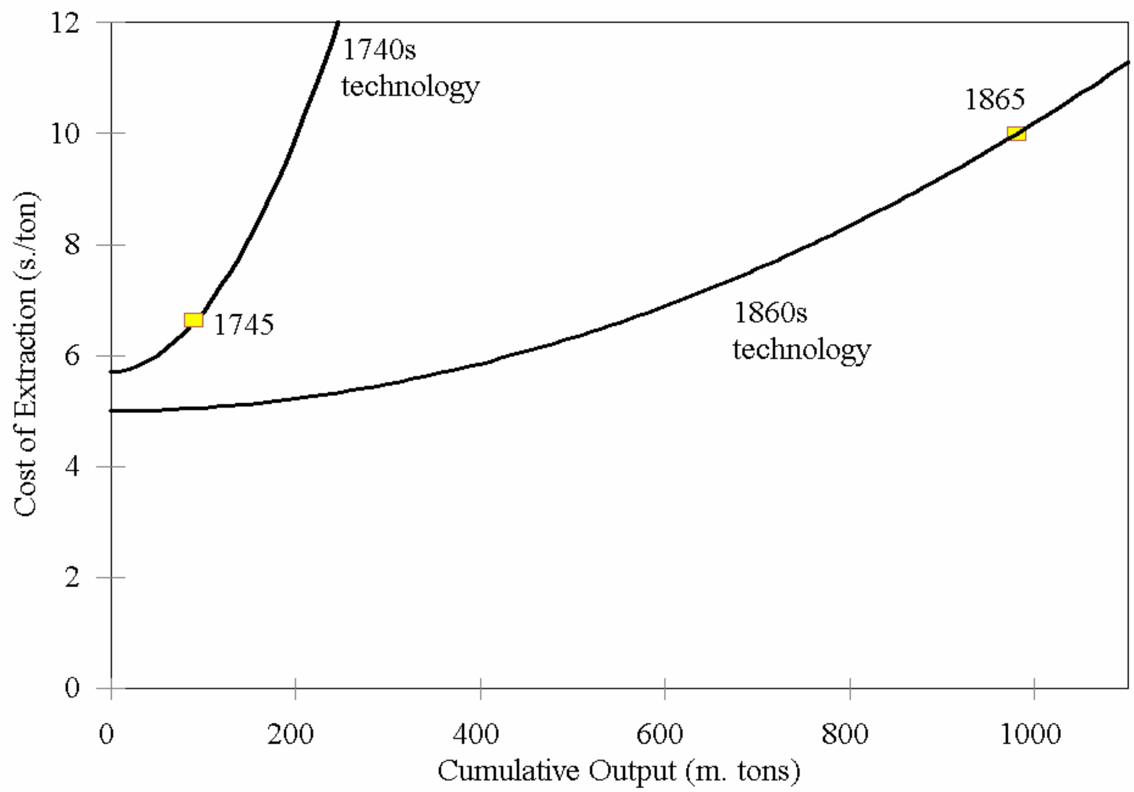
Sources: Outputs, Flinn (1984), p. 26, Church (1986), p. 3. London Prices, see appendix. General price level, Clark (2004).

Figure 2: The Modern Account of the Coal Industry in the Industrial Revolution



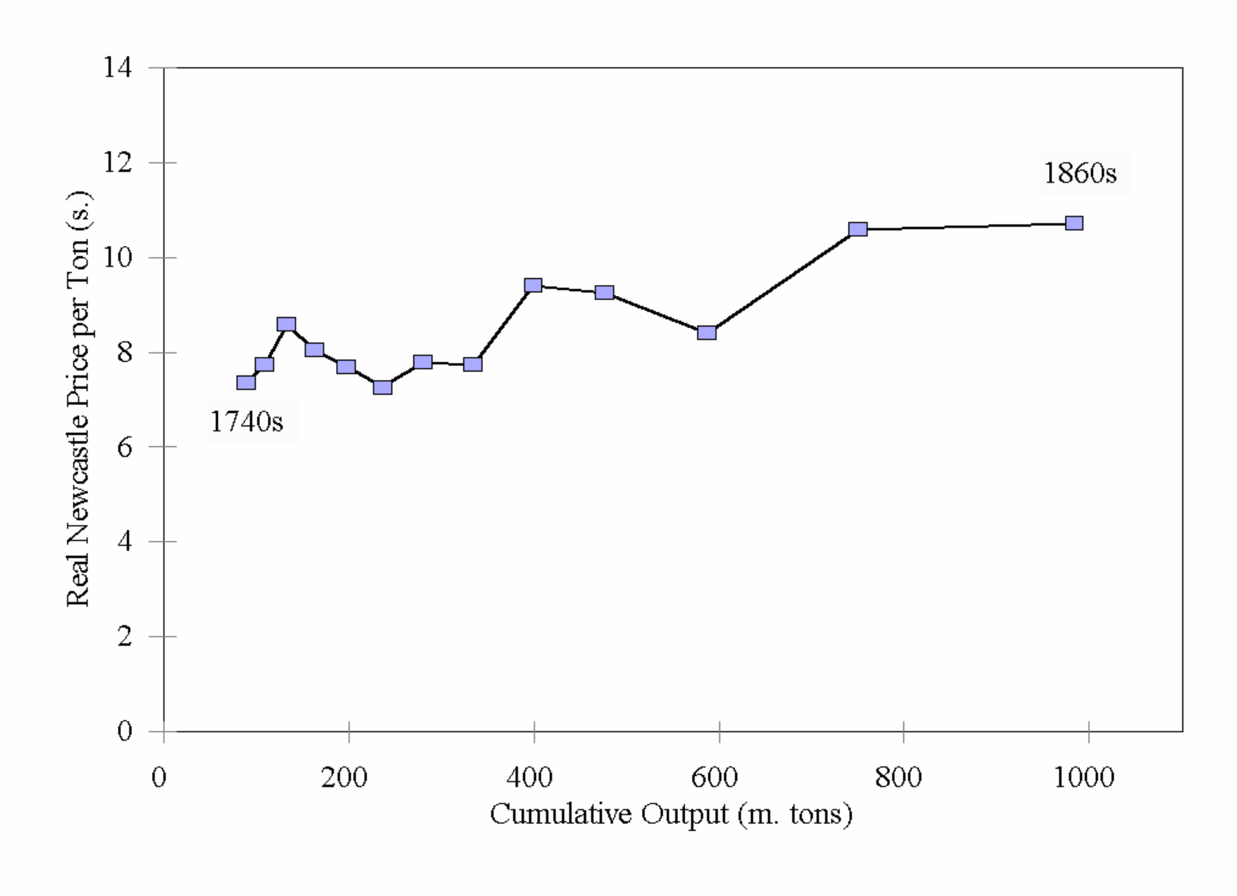
Source: See the text.

Figure 3: The Traditional Account of the Coal Industry in the Industrial Revolution



Source: See the text.

Figure 4: Real Newcastle prices per ton and cumulative output, 1740s-1860s



Note: The price is standardized to that of Wallsend coals. A Newcastle Chaldron was assumed throughout to be 2.65 tons. Actual Wallsend prices were available only for 1799-1835, the other years being estimated from the price series of other coals which overlapped this interval. Only some of these are true pithead prices, the others being the price of coal at the port of Newcastle. Prices were deflated by the cost of living index in Clark (2004).

Sources: See the appendix.

Table 1: Pithead coal prices in the northeast, 1740s-1860s (s./ton)

Decade	Wallsend	Mainteam	Percy Main	Tanfield Moor	"Best"	Exports - Newcastle	Exports – Shields, N & S	"Pithead" Average
1740s		4.34			4.53			4.68
1750s		4.45			4.34			5.21
1760s		5.28			5.66			6.15
1770s		5.43			5.09			6.30
1780s		5.45			6.89			6.17
1790s		5.56		5.87	6.98			6.70
1800s	10.41	7.55		8.47	12.38			9.74
1810s	12.61			9.43	14.57			10.80
1820s	11.96		11.23	9.38	14.48			10.66
1830s	10.91		10.34	8.30	12.40	6.36		9.62
1840s			7.30		11.02	7.19	7.88	8.48
1850s						8.27	8.11	10.20
1860s						8.75	8.46	10.72

Note: For our method of estimating average Newcastle prices per ton see the text.

Sources: See the appendix.

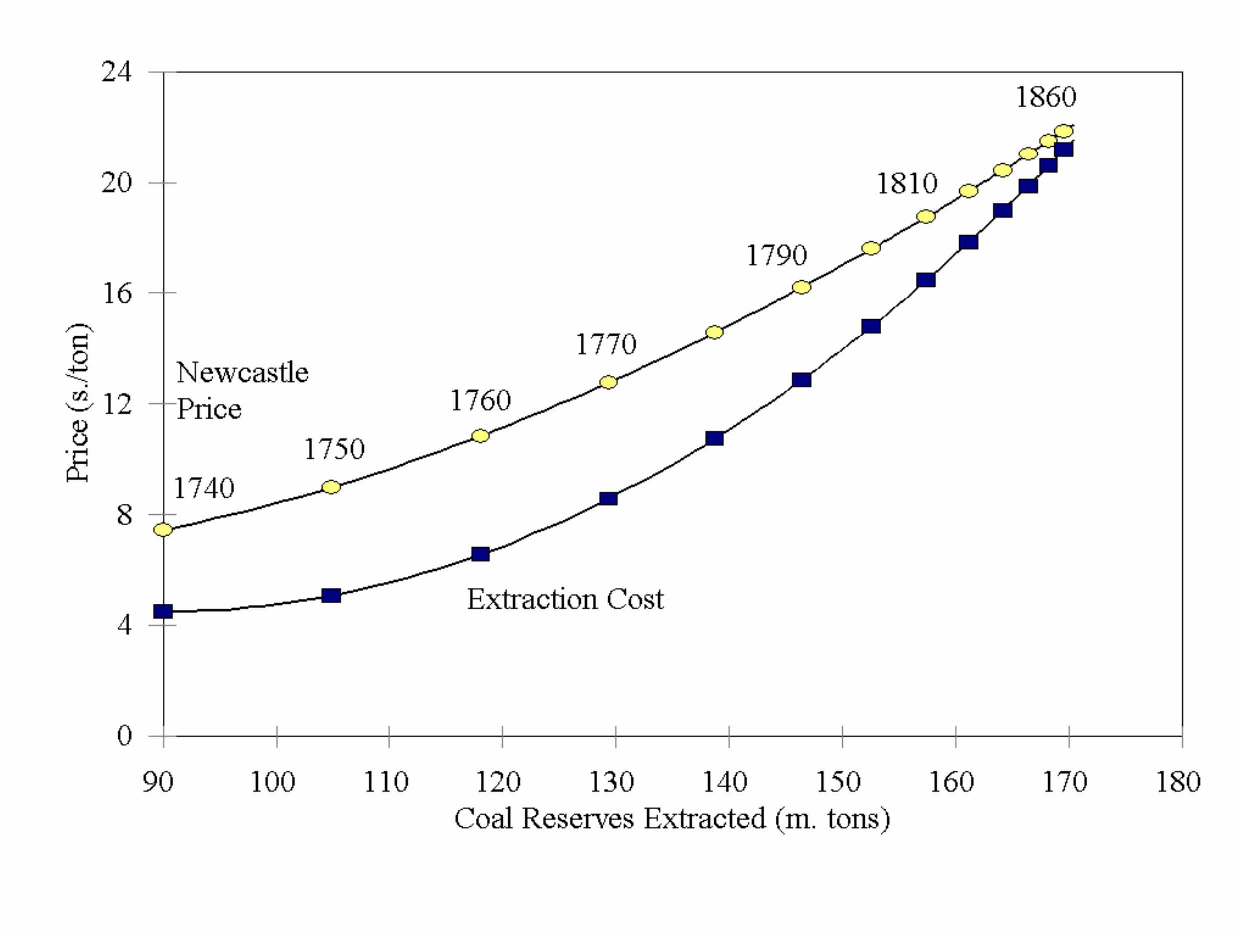
Table 2: Coal site rents in the northeast as a share of pithead prices

Decade	Number of leases	Average site rent per ton (s.)	Site rent as a % of Newcastle price	Minimum site rent (%)	Maximum site rent (%)
1740s	11	0.32	13.5	5.7	29.8
1750s	9	0.33	12.5	4.2	16.3
1760s	12	0.44	14.1	4.1	28.8
1770s	10	0.35	10.9	9.0	15.0
1780s	7	0.33	10.5	7.3	15.3
1790s	12	0.36	10.4	5.6	15.5
1800s	28	0.48	9.6	5.4	19.4
1810s	9	0.43	7.7	4.2	17.5
1820s	41	0.46	8.5	5.3	15.9
1830s	19	0.44	8.9	2.9	18.3
1840s	10	0.44	10.0	7.1	12.5
1850s	4	0.42	8.1	7.4	9.2
1860s	5	0.41	7.5	6.0	8.8

Note: For our method of estimating average site rents per ton see the text. The minimum and maximum rents are just the minimum and maximum reported rents per ton.

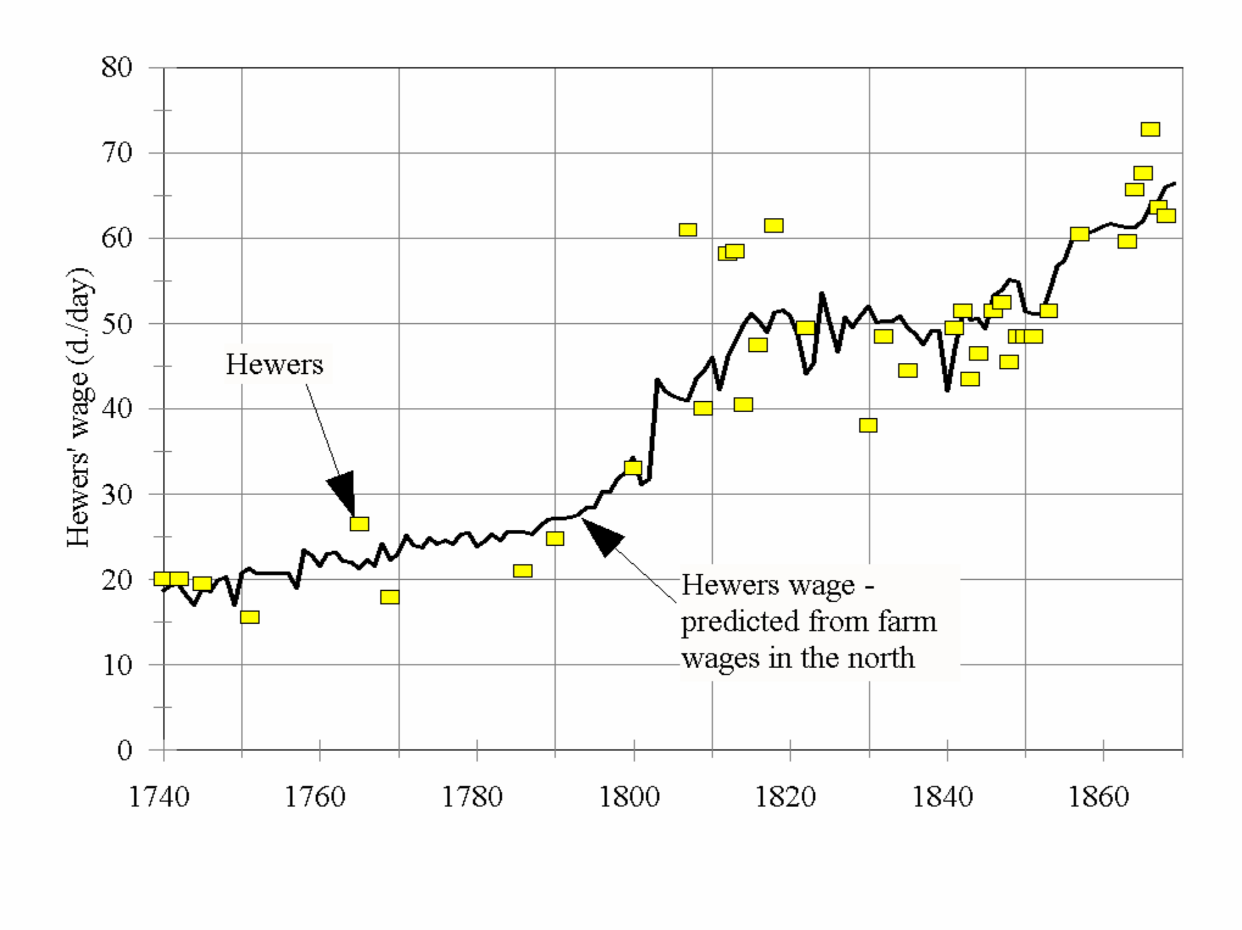
Sources: See the appendix.

Figure 5: Simulated path of prices and output from 1740 to 1860 with rapidly increasing extraction costs



Source: See the text.

Figure 6: Estimated hewers' wages in the northeast, 1740-1869



Notes: The solid line shows hewers wages in Northumberland and Durham as predicted from northern farm wages.

Sources: Hewers wages in Northumberland and Durham, Ashton and Sykes (1964), pp. 135-141, Flinn (1984), pp. 387-392, Church (1986), pp. 642-5. Farm workers wages in the north of England, Clark (2001).

Table 3: The Composition of Costs in Coal Mining, 1740-1869 (%)

Period	Coverage	Mining Labor	Horse Fodder	Pumping and miners' coal	Craftsmen and supplies	Ground rents	Capital
1740-1799	Northeast	40.9	-	7.1	14.8	11.3	21.5
1800-1830	Northeast	42.5	6.3	7.8	19.8	7.3	19.2
1830-1860	Britain	51.0[1]	-	-	-	-	20.0
Colliery Guardian, 1871	Britain	55.6[1]	3.3	3.7	9.6[2]	7.8	(20.0)
Assumed, 1740-1869		42.0	5.0	6.0	18.0	9.0	20.0

Notes: Costs were calculated net of taxes.

[1]Labor costs including craftsmen. [2]The costs of supplies only.

Sources: Flinn (1984), pp. 34-5, 292-3, 324-5, Church (1986), p. 502, 521-2,

Table 4: Estimated costs in north eastern coal mining, 1740s-1860s

Decade	Predicted Hewers' wages (d./day)	Northern Craftsmens' Wages (d./day)	Oats (s./bushel)	Hay (s./ton)	Timber (d./ft^3)	Bar Iron (d./lb)	Candles (d./lb)
1740s	17.5	15.3	1.49	47.2	7.8	1.47	5.91
1750s	19.6	15.7	1.62	48.0	8.9	1.36	5.70
1760s	20.9	18.7	1.74	49.1	9.3	1.37	6.15
1770s	22.8	19.8	1.91	60.9	9.9	1.39	6.51
1780s	23.6	20.4	2.01	69.9	9.6	1.57	6.80
1790s	27.0	24.1	2.60	76.2	13.0	1.44	7.48
1800s	36.7	33.5	3.50	97.4	22.2	1.77	9.66
1810s	45.1	40.2	3.74	110.5	25.3	1.54	10.48
1820s	45.5	37.2	2.85	91.5	17.1	1.21	6.37
1830s	46.4	36.6	2.74	81.7	15.5	0.96	5.23
1840s	47.2	37.3	2.65	74.3	12.4	0.79	5.07
1850s	52.5	40.3	2.76	71.4	9.1	0.80	5.62
1860s	58.6	43.9	2.89	82.3	9.4	0.73	6.11

Sources: Farm wages, Clark (2001). Building wages, candles, Clark (2004b). Oats, hay and timber, Clark (2004a).

Table 5: Estimated capital costs, 1740s-1860s

Decade	Brick Prices (s./100)	Capital Price (p_k) (1860s = 100)	Capital Price, Church (1860s = 100)	Bond and Mortgage Rate (%)	Capital Rental Costs (1860s = 100)
1740s	2.03	44.4	-	4.14	41.6
1750s	1.58	46.4	-	4.11	43.3
1760s	1.89	50.8	-	4.30	48.4
1770s	1.93	54.1	-	4.39	52.1
1780s	1.97	56.1	-	4.69	55.7
1790s	2.76	65.5	-	4.71	65.1
1800s	3.97	91.1	-	4.85	92.0
1810s	4.56	106.1	-	4.86	107.3
1820s	4.14	97.6	-	4.69	96.9
1830s	3.77	94.1	96.7	4.69	93.5
1840s	3.36	90.4	93.9	4.75	90.4
1850s	2.96	92.7	95.7	4.62	91.4
1860s	3.20	100.0	100.0	4.76	100.0

Notes:

Sources: Capital costs, Church (1986), p. 177.

Table 6: Net Returns on Coalmining Capital, UK, 1850s, 1860s

Year	Net UK Coal Profits (£ m.)	Estimated Mining Capital (£ m.)	Net Rate of Return (%)
1854	[a]1.29	[a]25.6	5.04
1856	[a]1.32	[b]21.6	6.11
1860	[a]1.52	[c]28.0	5.42
1866	[a]2.14	[a]39.5	5.42
1866	[a]2.14	[b]34.3	6.24

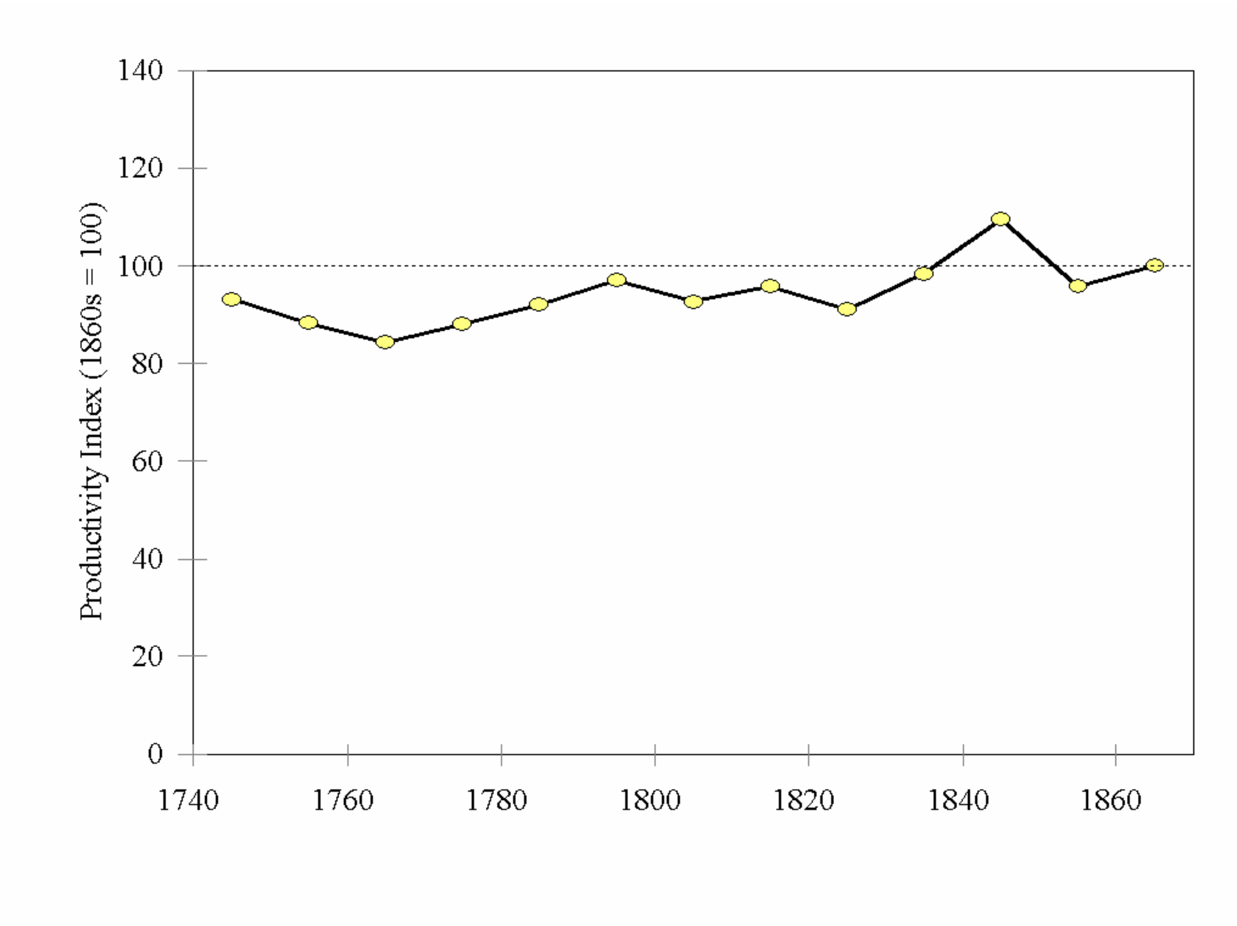
Sources: [a]Church (1986), pp. 103, 530-1, [b]Mitchell (1984), [c]Buxton (1978).

Table 7: Estimated pithead prices, costs and TFP in the northeast, 1740s-1860s

Decade	Pithead Prices (1860s = 100)	Costs (1860s = 100)	TFP (1860s = 100)
1740s	43.7	40.7	93.2
1750s	48.6	42.9	88.4
1760s	57.4	48.4	84.4
1770s	58.8	51.8	88.1
1780s	57.5	53.0	92.1
1790s	62.5	60.7	97.1
1800s	90.8	84.2	92.7
1810s	100.7	96.5	95.8
1820s	99.4	90.6	91.1
1830s	89.8	88.4	98.5
1840s	79.1	86.7	109.5
1850s	95.2	91.3	95.9
1860s	100.0	100.0	100.0

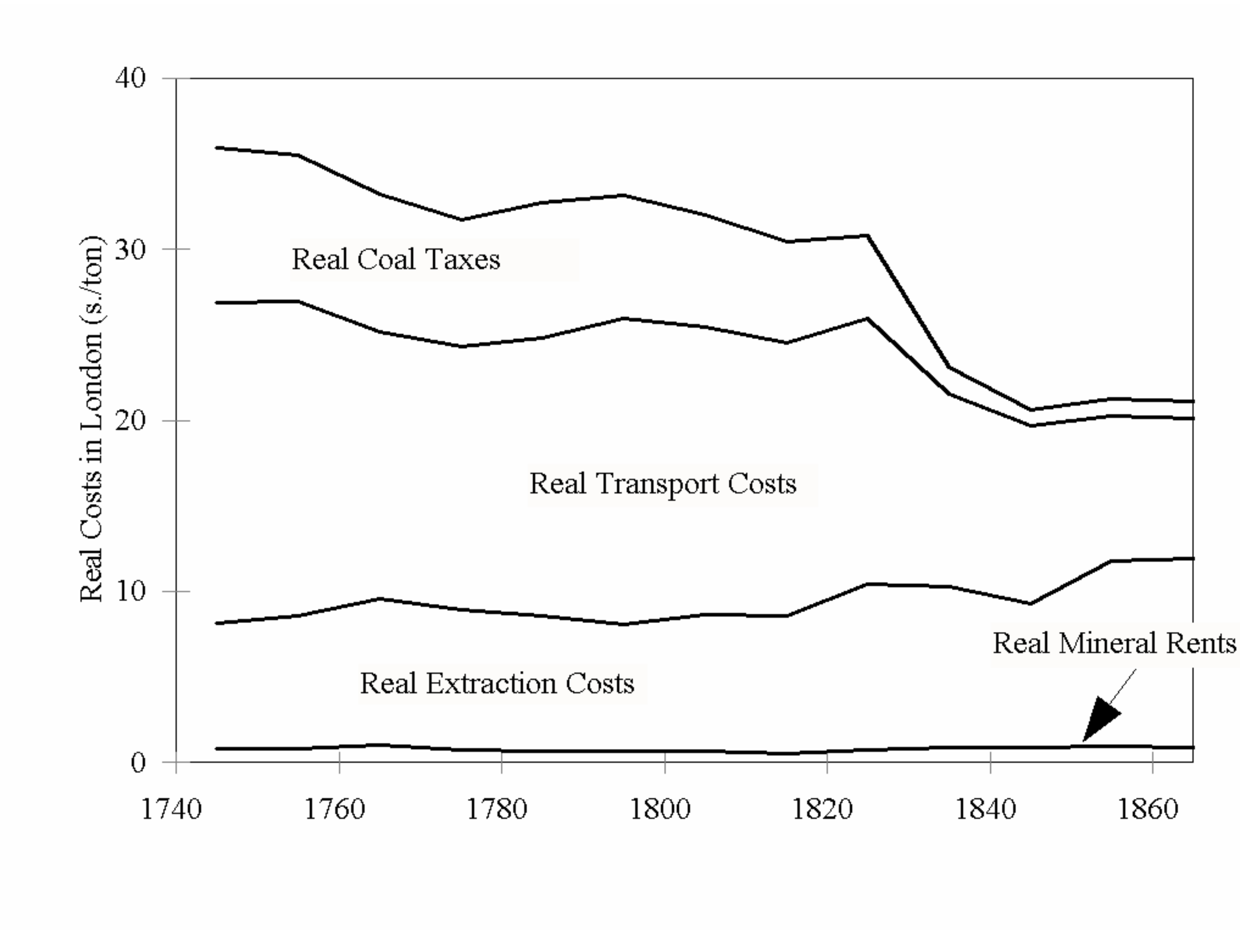
Sources: Tables 1-5.

Figure 7: Total factor productivity in north east mining, 1730-1869



<u>Source</u>: Table 7.

Figure 8: The Elements of the Real Cost of Coal in London, 1740-1869



<u>Source</u>: See the text.

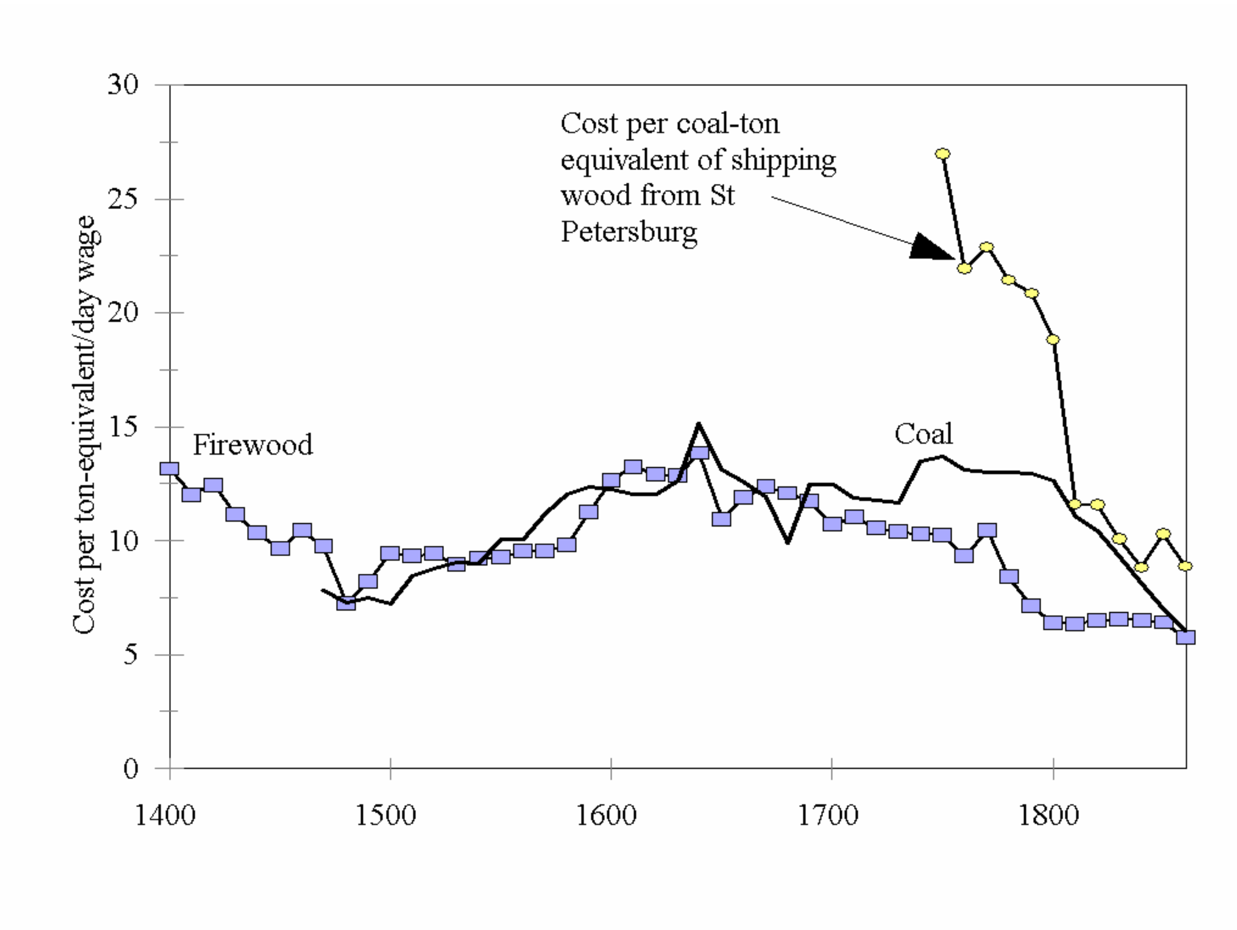
Table 8: Potential Fuel Supplies Available to England in the Industrial Revolution Era

Region	Area (m. acres)	Forest area 2000 (m. ac)	Forest output c. 2000 (m. ft^3)	Equivalent tons of coal (m)	Output/Acre 2000 (ft^3)
England	32.23	-	-		-
BALTIC/ARCTIC	**812.48**	**472.21**	**8,552**	**79.9**	-
Baltic Republics	43.00	17.24	679	6.3	39.4
Belarus	51.30	23.23	627	5.9	27.0
Finland	83.26	54.20	1,784	16.7	32.9
Norway	80.06	21.91	291	2.7	13.3
Sweden	111.10	67.05	2,055	19.2	30.7
Poland	77.06	29.28	919	8.6	31.4
North West Russia	366.69	259.27	2,196	20.5	8.5
BRITISH NORTH AMERICA	**738.21**	**431.78**	**3,082**	**28.8**	-
New Brunswick	18.15	15.09	360	3.4	23.8
Newfoundland	99.96	55.66	90	0.8	1.6
Nova Scotia	13.71	9.69	214	2.0	22.1
Ontario	224.27	143.31	929	8.7	6.5
Prince Edward Island	1.40	0.73	22	0.2	30.4
Quebec	380.71	207.31	1,466	13.7	7.1
ALL	**1,550.69**	**903.98**	**11,634**	**108.7**	-

Sources: United Nations, Food and Agriculture Organization, Forest Products. Statistics Canada.

Notes: North West Russia is taken as including the Arkhangelsk, Karelia, Komi, Leningrad, Murmansk, Novograd, Pskov, and Vologda Oblasts.

Figure 9: The Cost of Coal and Wood as Energy Sources, 1400-1869



Notes: This figure is drawn on the assumption that a standard hundred of deals in St Petersburg occupied 165 cubic feet (Lower (1973), p. 25).

Sources: Clark (2004a), Clark (2004b), Harley (1988)